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Changes in travel mode choice research during the pandemic era: A scientometric review based on citespace

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ABSTRACT

With the disappearance of the pandemic, have the pandemic's effects also totally vanished now and how to scientifically determine whether it has already ceased? It is still essential for future transportation. **Objective.** To analyses travel mode choice (TMC) research during the pandemic era primarily. **Methodology.** To enrich such reviews and better understand the research situation and changes of TMC due to the COVID-19, 972 articles of WoS from 2019 to 2023 under the transportation category are selected for a

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scientometric review analysis based on CiteSpace. **Results.** This study not only mapped main characteristics like authors, journals, keywords and critical articles, but also dug into the new cluster COVID-19 pandemic and showed the changes. These results indicate that the pandemic has brought tangible changes to mode choice, transformed the behavioural models and expanded the disciplinary scope, themes, and factors in the TMC study. **Conclusion.** The question of whether the pandemic's influence will completely disappear must be determined by assessing risk perception, psychological factors, remote work, and policies that still influence public transportation behavior. This will help us understand future public transportation behavior and offer insights for transportation planning in a post-pandemic world.

KEY WORDS: Travel Mode Choice, Pandemic Era, Emerge factors, Scientometric Review, Citespace.

Introduction

Research on travel mode choice (TMC) is not only a crucial component of travel behaviour research but also a key basis for traffic demand forecasting, transportation planning, and passenger flow assignment. Understanding the research status and its changing trends in this field is of great significance for future transportation. In particular, certain major events or research findings may even influence the research direction and development of a field. In recent years, the COVID-19 pandemic has been one of the major events that has occurred with far-reaching impacts.

COVID-19 began with a massive outbreak of infections at the end of 2019, and the World Health Organisation declared it no longer a public health emergency of international concern in May 2023. A lot of things have changed after experiencing this big event. Many studies from countries around the world show that COVID-19 has had a huge impact on travel behaviour, especially on the TMC change.

Now that the pandemic has nearly receded entirely, attention to it has faded, as if its impacts have come to an end—but is this truly the case? Some studies indicate that the

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post-pandemic recovery and rebound in TMC have not offset the effects brought about by the pandemic's outbreak, and sustained changes and impacts persist. It is widely recognised that the pandemic altered residents' travel modes during its outbreak and prevalence; however, it remains unclear whether the pandemic exerts a sustained impact on TMC in its subsequent recession phase, or in which specific aspects such impacts persist. To address this question, it is first necessary to clarify and understand the research status of TMC during both the pandemic period and its recession phase.

Although many scholars have published varied research results on travel behaviour before, the global research overview mainly focuses on traditional research topics such as travel behaviour change and factors that affect travel behaviour. The research review on TMC during COVID-19 influence time remains insufficient. Therefore, to address this research gap, this study first conducts a review of TMC research within the transportation field spanning the five-year period from 2019 to 2023, a timeframe that encompasses the outbreak and prevalence of the pandemic.

To better understand and focus, this study will only focus on the research topics of urban residents' TMC, and the TMC research related to tourism categories is not included in the scope of this review. The overall purpose of this study is to conduct a scientific econometric review of the academic literature published in the field of TMC (transportation) from 2019 to 2023.

Specifically, this review had three objectives:

identifying the main characteristics of TMC research from 2019 to 2023—including the most influential authors, countries, institutions and keywords in the field, as well as research hotspots and evolutions; offering a concise overview of the field via a knowledge map; discussing changes and new insights in the field from the pandemic revealed by the review, and proposing the aspects that should be considered to measure the sustained impact of the pandemic on TMC during the pandemic-free period.

The study is structured as follows: the next section outlines the research methodology, covering data sources and analytical techniques; subsequent sections present and synthesise the scientometric review results into a knowledge graph. Finally, the discussion and conclusions section puts forward new insights and future research

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outlooks, considering aspects that should be measured to assess the sustained impact of the pandemic on TMC during the pandemic-free period.

MATERIALS AND METHODS

Scientometrics is a scientific mapping technique that systematically examines academic literature via domain analysis and visualisation, applicable to a discipline, field, or topic (Chen, 2017). By using specific software (CiteSpace, VOSviewer, Bibexcel, and CitNetExplorer) to analyse "a set of bibliographic records of research areas and generate an overview of basic knowledge". Quantitative techniques are used to analyse bibliographic records, such as article titles, authors, keywords, journal titles, and cited references. Similar to narrative reviews, they provide a broad literature review—distinct from systematic reviews that target specific research questions. With broader insights than other methods, they can effectively outline a field. Scientometric reviews are increasingly being conducted in the field of transportation to examine whole fields and specific topics, including travel behaviour.

Search strategy and data collection

The goal of this review is to naturally identify the period-specific characteristics of the TMC research field and their links to COVID-19. Thus, the search query was designed to retrieve the widest possible range of articles from this period.

Data were collected from the Social Sciences Citation Index (SSCI) and Science Citation Index Expanded (SCI-EXPANDED), both part of the Web of Science (WoS) Core Collection. WoS is widely regarded as one of the most appropriate databases for scientometric analysis, and other researchers have previously used it—primarily due to its indexing of numerous high-quality peer-reviewed journals and compatibility with analytical software.

Search queries use the advanced search feature to find a Subject Term (TS) in the Title, Abstract, Author Keywords, and Keywords Plus (words generated from frequently used words in WoS) fields of a record using the TS as the search term. Additionally, the search was limited to the WoS category (WC) of Transportation, which includes 51 journals, and 98% are English language. As the focus of this study was TMC research, the inputted

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search term was- TS= "travel mode choice" OR TS="mode choice" AND WC = "Transportation". Additional search filters were only journal articles and a time frame of 2019–2023.

The WoS search was conducted on 12th March 2025. A total of 972 articles were collected after screening the pre-published papers in 2024 and 2025. The bibliographic data for each article were extracted from WoS and imported into the data analytics and visualisation software program CiteSpace v6.4.R2 (Chen, 2017). The bibliographic data included: author's name, institute, country, article name, journal title, research category, keywords, abstract and cited references. Table 1 shows the basic information of our final data

Table 1. Basic Information of Final Data.

Criteria	Quantity
Articles	972
Journals	35
Authors	2539
Institutions	2142
Countries	235
Cited references	366

Data analysis

CiteSpace is a Java application for scientometrics. CiteSpace is a tool designed for conducting a visual analytic study of the scholarly literature of a research field, or a discipline, collectively known as a knowledge domain. We used CiteSpace v6.2.R4 to retrieve co-citation networks using references, authors, institutions, countries, and co-occurrence networks with keywords as the unit of measure.

To ensure the inclusion of the highest-quality publications, we adopted CiteSpace's default g-index— which ranks publications by citation counts as an indicator of academic quality and productivity—as the selection criterion. The default scaling factor (k=25), designed to control network size in CiteSpace, was used, with its value proportional to the resulting network scale.

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To address the initial research objective, we performed a comprehensive analysis in accordance with the procedure outlined in Figure 1. The analysis carried out is detailed in the relevant results section through social network analysis, co-occurrence analysis, cluster analysis, the dual-map overlay analysis, and article structure variation analysis with the help of CiteSpace. Among these methods, Social network analysis is used to characterise cooperative relationships between authors, institutions, and countries and to identify key intermediaries. Co-occurrence analysis depicts the structure of a research topic through the co-occurrence relationship of keywords or terms (Chen, 2017). Cluster analysis groups nodes in co-occurrence or co-citation networks by similarity to form thematic clusters, thereby revealing research hotspots, subfields, and their evolutionary trends within a given domain. Dual-map overlay analysis for visualising cross-disciplinary knowledge flows and citation paths (Chen, 2017), and structural variation analysis for assessing the potential of new publications to restructure the intellectual landscape of a field (Chen, 2012).

In CiteSpace, analytical results are interpreted via network and content-based indicators: Node size usually reflects an entity's (paper/author/journal) total citations—larger nodes = higher citation frequency, betweenness centrality (identifies pivotal nodes bridging research communities and potential paradigm shifts); citation burstness (temporal indicator, with red spurts marking spike periods to highlight high-citation-growth documents for emerging trends); modularity (Q-value >0.3 = significant clustering) and silhouette score (S-value: >0.3 = homogenous, >0.5 =reasonable, >0.7= highly credible, both for evaluating clustering); sigma (combines centrality and burstness to measure transformative potential); structural variation metrics (e.g., modularity/cluster linkage changes, assesses new publications' impact on a field's intellectual structure).

To achieve the second objective of the review, the main results of these analyses were synthesised into a knowledge graph of TMC research, creating a summary vision of the field. As for the third objective, we focus on keyword topics, clusters, key papers and their evolutionary trends related to the pandemic during this period, capturing the part that can be assessed in the pandemic-free stage.

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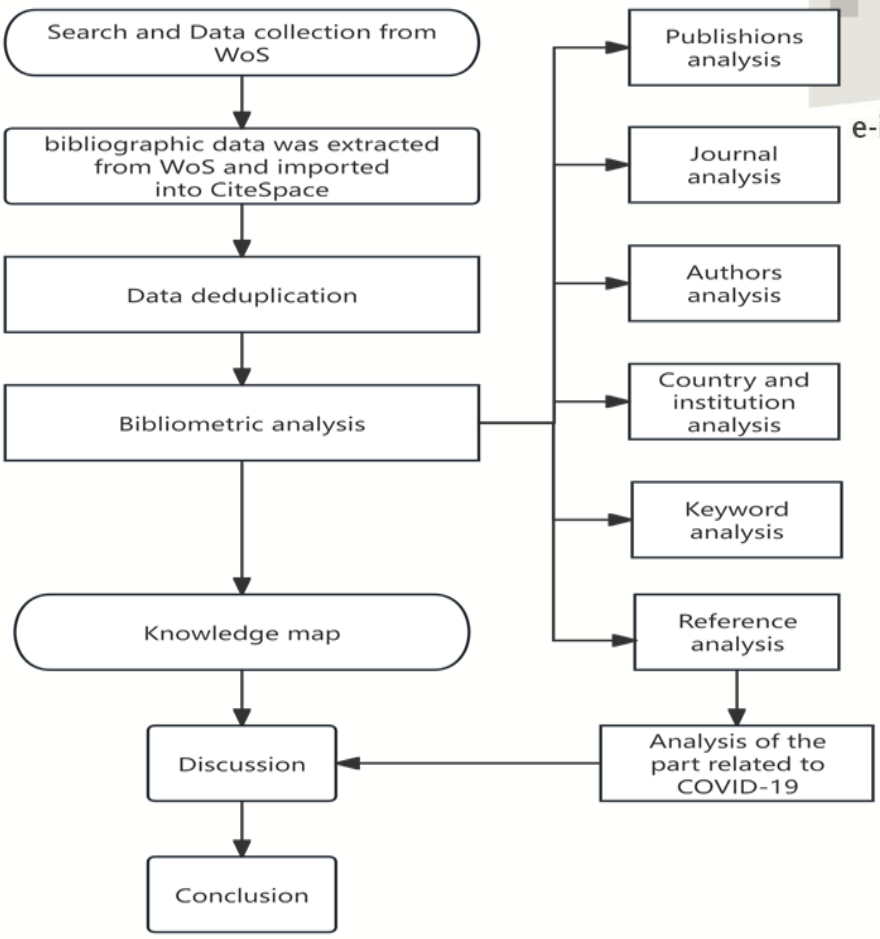

Figure 1. Analysis process

Main characteristics

Publication analysis

A total of 972 articles on TMC research were identified and included in the scientometric review and are referred to as “identified articles”. Figure 2 shows the quantity of identified articles published annually from 2019 to 2023. Against the overall growth trend of research outputs, there was a more significant increase in 2021, followed by a decline in 2022, and then another rise in 2023. Since 2021 and 2022 were still within the fluctuating period of the pandemic, this suggests that research outputs in this field may have been affected by the pandemic.

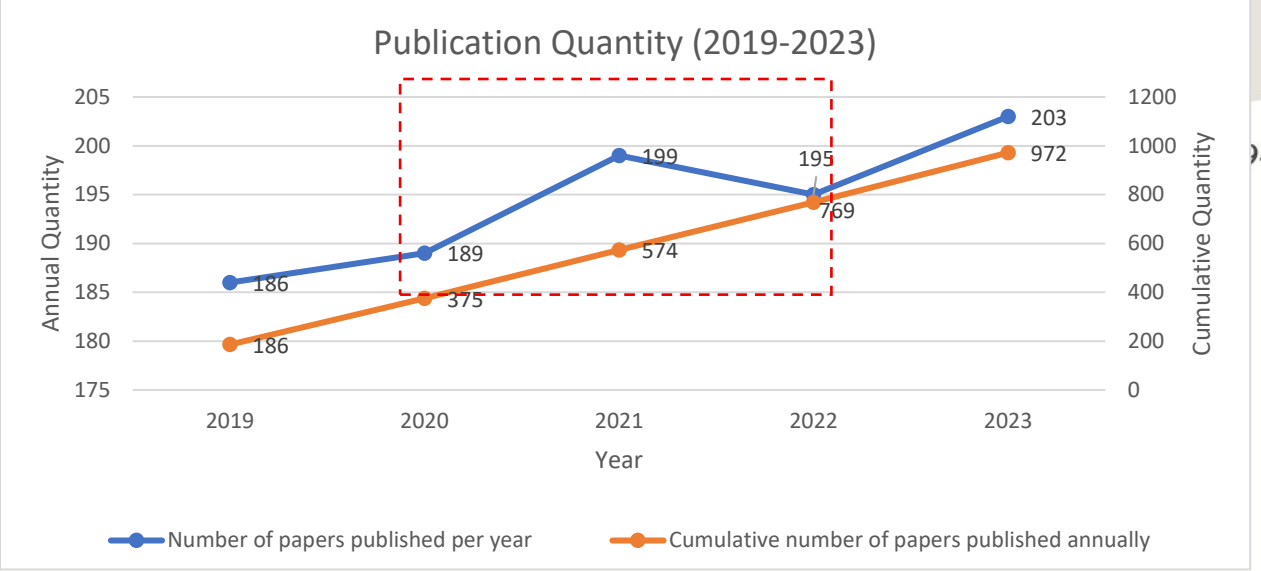

Figure 2. The number of identified articles published per year from 2019 to 2023

Country and institution analysis

An examination at the country and institution levels can unveil whether specific countries or institutions hold significant prominence within a field during this period. To ascertain the presence of notable research groups associated with the top five most productive institutions, an extensive examination of the bibliographic data within WoS was carried out for every journal article published by these institutions.

As Table 2 shows, the most active countries with high frequency were the USA, China, and England. Among them, the USA not only has high frequency but also has a high centrality, showing its importance and wide influence. China has produced many research achievements, but its collaborative influence is still rather limited. England is followed by the USA and China, but has the highest centrality, showing its high levels of collaboration. So, it can be considered that England, the USA, China and the Netherlands have played an excellent role as research bridges and intermediaries from 2019 to 2023.

Table 2. Top 10 prolific countries

NO.	Country	Freq	Degree	Centrality
1	USA	248	36	0.37
2	PEOPLES R CHINA	228	27	0.17

NO.	Country	Freq	Degree	Centrality
3	ENGLAND	103	35	0.39
4	CANADA	84	18	0.09
5	NETHERLANDS	79	29	0.23
6	AUSTRALIA	68	19	0.03
7	GERMANY	61	19	0.03
8	INDIA	40	9	0
9	JAPAN	39	19	0.07
10	BELGIUM	33	21	0.06

The main research groups identified are shown in Figure 3. The University of Leeds, Indian Institute of Technology System (IIT System), and the University of California System are the top three prolific institutions. The Swiss Federal Institutes of Technology has the highest value in the betweenness centrality showing its broadness of cooperation. Because the IIT System has both high yields and extensive cooperation, it is considered to hold significant prominence within a field during this period. These institutions are mainly located in England, the USA, the Netherlands, China and Swiss.

Figure 3. Institutions Network Analysis

Authors analysis

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Citespace can help us find authors who make a lot of effort in this research topic. There are 2539 authors identified. Table 3 shows the top ten authors with the most co-occurrence counts. The top three ranked authors are De vos, Jonas (frequency = 22), Habib, Khandker Nurul (frequency = 11), Witlox, Frank (frequency = 10). Furthermore, the frequency, degree, and centrality of De vos, Jonas is the top of all authors. Meanwhile, the analysis of the cooperative network in Figure 4 shows that there is closer cooperation between scholars around De vos, Jonas. Therefore, we think that he is a core figure in this field during this period, playing a crucial and indispensable role in academic output, knowledge dissemination, and academic cooperation. He has a significant influence on promoting the development of this field. Their research achievements and academic viewpoints are likely to receive widespread attention. Moreover, they serve as a leader and a bridge in the development of the discipline, being a key and indispensable figure in the academic network of this field during this period.

Table 3. Top 10 most co-occurrence counts authors.

NO	Author	Freq	Degree	Centrality
1	De vos, Jonas	22	15	0.02
2	Habib, Khandker Nurul	11	3	0
3	Witlox, Frank	10	9	0
4	Wang, Donggen	10	3	0
5	Axhausen, Kay W	8	4	0
6	Mehdizadeh, Milad	8	3	0
7	Nordfjaern, Trond	8	2	0
8	Cheng, Long	7	7	0
9	Cats, Oded	7	5	0
10	Ettema, Dick	6	3	0.01

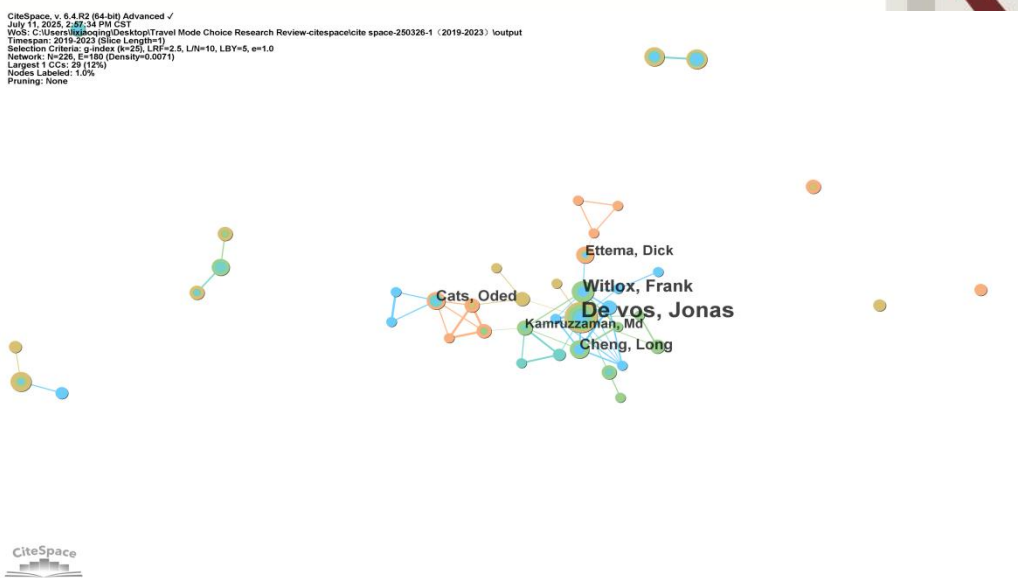

Figure 4. Network analysis of the main co-authors.

Main Journals

972 identified articles cited 35 distinct peer-reviewed journals. Table 4 presents the top 10 most active journals, reflecting their importance in the field. Notably, the Transportation Research journal series is highly active in this domain, with three of its titles ranking among the top 10. Among these, Transportation Research Part A excels in citation frequency, degree, and centrality—indicating it was an indispensable hub journal for TMC research from 2019 to 2023. It was followed by Transportation, Transportation Research Record, Transport Policy, and Journal of Transport Geography.

Table 4. Top 10 Active Journals (rank by Frequency)

NO.	Journals	Freq	Degree	Centrality
1	Transportation Research Part A: Policy and Practice	865	52	0.05
2	Transportation	740	46	0.02
3	Transportation Research Record	734	48	0.03
4	Transport Policy	676	40	0.01
5	Journal of Transport Geography	665	48	0.03

NO.	Journals	Freq	Degree	Centrality
6	Transportation Research Part D: Transport and Environment	578	45	0.02
7	Transport Reviews	518	33	0.01
8	Transportation Research Part B: Methodological	427	33	0.01
9	Travel Behaviour and Society	382	30	0
10	Transportation Research Part F: Traffic Psychology and Behaviour	347	37	0.02

Since we have limited the category of WoS when searching for article data, we are all journals in the transportation category. Table 4 shows that the research interests of TMC mainly involve transportation policy, behaviour and society, geography environment, as well as the research reviews. It reflected that the study of TMC plays an important role in promoting the research and practice of transportation in these directions. In these years, the changes in transportation policies caused by the pandemic have indeed had a significant impact on travel and attracted greater attention.

Journal Knowledge Sources

To illustrate the interdisciplinary relationships in TMC research, we performed a dual-map overlay analysis of scientific mapping literature. The left side represent the disciplinary distribution of journals in which the currently analyzed literatures are published, as well as the source disciplines of the cited literatures and the right-hand side indicates the disciplinary distribution of journals for the cited literatures targeted by these citations; Arcs represent citation relationships, flowing from the citing disciplines to the cited disciplines and line colors typically indicate time sequences (cool colors: earlier periods, warm colors: recent periods), while line thickness denotes citation frequency (thicker lines signify more frequent interdisciplinary citations) (Chen, 2012).

Figure 5 reveals that the knowledge carriers of TMC—reflecting the research frontiers—are predominantly distributed in the left-hand clusters, including 1# methematics, systems, mathematical, 3# ecology, earth, marine, 5# physics, materials, chemistry, 7# veterinary,

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animal, science 2# medicine, medical, clinical, 6# psychology, education, health. Conversely, the right-hand side presents information sources, primarily comprising referenced journal articles, including 12# economics, economic, political, 7#psychology, education, social,13# revista, psicologia, saude 18# history, philosophy, records,1# systems, computing, computer,8# molecular biology, genetics. Among these clustered terms, words related to medical health and psychology can be observed. This may be attributed to scholars' increased attention during the pandemic to the role of different travel modes in the spread of infection, the potential threats to passengers' health, as well as the psychological factors.

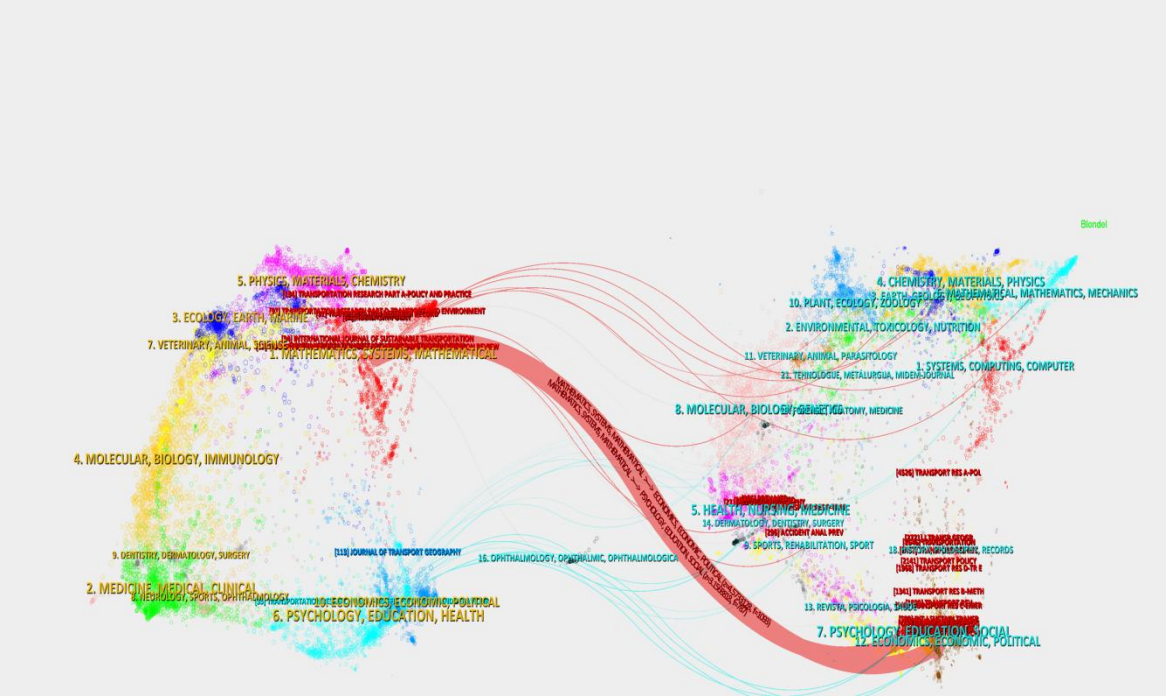

Figure 5. Dual-map overlay graph of journals.

On the left-hand side, we discover a few important journals, including Transportation Research Part A Policy and Practice (134 citing articles), Transportation Research Part D：Transport and Environment (97 citing articles). Additionally, on the right-hand side, we can see some representative cited journals that are related to the TMC, including Transportation Research Part A Policy and Practice (frequency = 4,526; the frequency denotes the number of papers published in this journal on the topic of the TMC), Journal of Transport Geography (frequency =2771), Transportation (frequency = 2,646).

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Through analysing the TMC journal domain distribution and knowledge flow, we find that in the figure, thick red lines (high-frequency path) connect distinctly different disciplinary clusters from the same disciplinary group, (methematics, systems, mathematical → economics, economic, political / psychology, education, social). This indicates that there exists interdisciplinary knowledge flow, and the citation activities within the dataset are mainly concentrated among specific disciplines such as economics, political science, psychology, education, and sociology. Some red thin paths connecting clusters reflect emerging interdisciplinary research disciplines, specific as 1: systems, computing, computer.

In general, TMC research is a complete study of several fields, with multidisciplinary and diverse features. During this period, the research topic primarily flowed from disciplines such as mathematics, physics, ecology, and psychology to disciplines including psychology, education, economics, social, politics, health, environment, and computer science, which are more close to the COVID-19 situation.

keyword Analysis

To reveal the thematic structure, hotspots of research on TMC during this period, keyword co-occurrence and cluster analyses were conducted. In the keyword co-occurrence analysis, the time slice was set to one year, Top N = 50, and the LLR algorithm was employed to generate cluster labels. A total of 372 keywords were extracted, forming 1,974 co-occurrence links, with a network density of 0.0286, indicating that the thematic distribution in this field is relatively dispersed but maintains certain interconnections. The low-density characteristic suggests a clear partitioned structure among research themes, facilitating the identification of distinct research hotspots and frontier clusters.

High-frequency keywords reflect the core themes of the research domain. As Figure 6 shows, the top ten high-frequency keywords with a high degree included: “travel mode choice, built environment, land use, attitudes, walking, residential self-selection, car ownership, urban form, active travel, car use.”, which reveals these topics studied most by researchers in this field from 2019 to 2023.

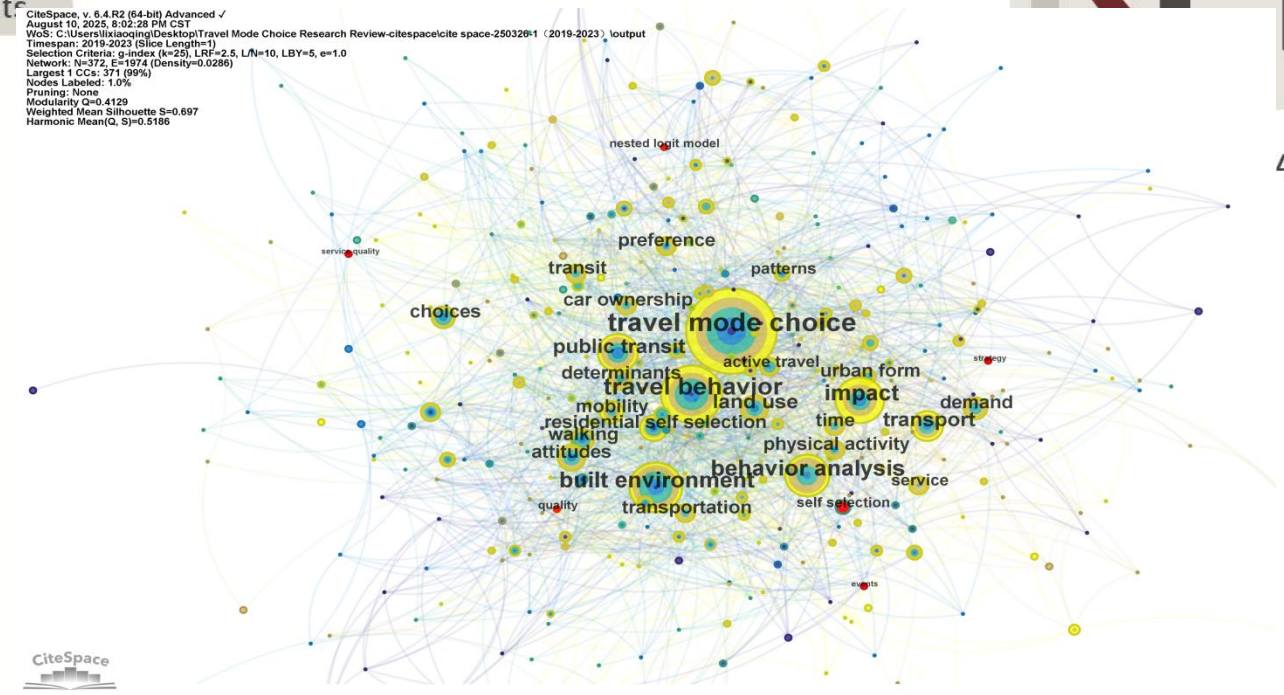

Figure 6. Keyword co-occurrence analysis (by Freq)

The most frequent keyword, “travel mode choice” (Freq = 628, Degree = 20, Cluster #4: autonomous vehicle), suggests that TMC is the core research theme in this field and is closely related to the application context of autonomous vehicles. Other high-frequency keywords, such as “built environment” (Freq = 231, Degree = 21) and “land use” (Freq = 98, Degree = 22), highlight the importance of urban built environment and land use patterns in understanding residents’ TMC. Within the same cluster (Cluster #4), keywords such as “car ownership” (Freq = 65, Degree = 23) and “urban form” (Freq = 65, Degree = 21) exhibit high degree values, indicating direct connections to multiple research topics and suggesting their potential role as bridges between different research communities. It also indicates that research on TMC has primarily focused on the interaction between travel behaviour and urban spatial structure.

In addition, “attitudes” (Freq = 88, Degree = 20) and “residential self-selection” (Freq = 72, Degree = 20) show that the influence of individual psychological factors and residential choices on TMC has become a focal point of research during this period.

Cluster analysis of keywords shows their development over time through timeline graphs. As Figure 7 shown, the top 10 clusters include: Cluster #0 ride-sourcing service, Cluster #1 life satisfaction, Cluster #2 households mobility behavior, Cluster #3 active school

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travel, Cluster #4 autonomous vehicle, Cluster #5 preference survey, Cluster #6 everyday mobility, Cluster #7 stated preference survey, Cluster #8 explaining travel, Cluster #10 trip chaining; The largest cluster (#0) has 70 members with a silhouette value of 0.644. The most cited members in this cluster are: time, demand, choices, transit, service. The second largest cluster (#1) has 47 members with a silhouette value of 0.66. The most cited members in this cluster are: mobility, accessibility, car, elderly people, work. The third largest cluster (#2) has 47 members with a silhouette value of 0.656. Car use, planned behaviour, satisfaction, commute mode choice, bicycle are the most cited members in this cluster. It shows these topics are the main research themes in TMC. In addition, the keyword "COVID-19" appears in Cluster #2, which shows that the pandemic context has an impact on the households' mobility behaviour.

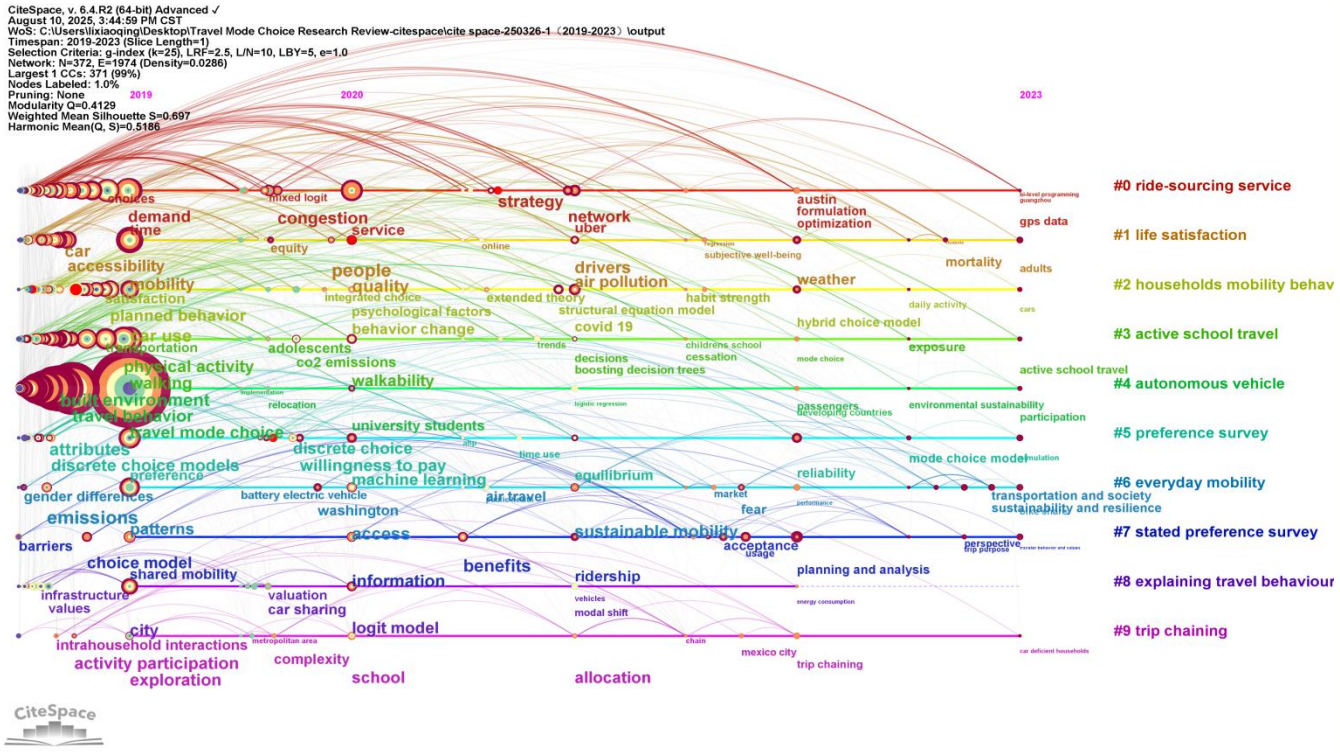

Figure 7. Timeline view of keyword analysis.

Reference Analysis

One essential aspect of scientometric reviews is their capacity to analyse frequently cited references within a field, which aids in constructing an understanding of the intellectual

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foundation of that field (Wang et al., 2018). A reference analysis was conducted, which compares the frequency of references that were jointly cited by the 972 identified articles. The main and most critical references were identified, and a cluster and Structure Variation Analysis (SVA) analysis was conducted to develop a thorough understanding of the field. Figure 8 displays the temporal evolution of the cited reference, which is represented by the node carrying the information “name of the author and year of publication”. The number of times the article has been co-cited is indicated by the node size; hence, the bigger the node size, the more influential the article is in the field of study. In addition, we can also observe the bridging papers with high betweenness centrality (purple rings) and the pivotal papers with citation bursts (red dots) across different years.

Pivotal articles and clusters

We performed a clustering analysis, the citation bursts and centrality bursts of the literature and visualised the distinct clusters in a timeline map. The top 5 clusters of reference are Cluster #0 non-linear association, Cluster #1 travel satisfaction, Cluster #2 residential self-selection, Cluster #3 autonomous vehicle, Cluster #4 identifying profile. At the same time, we can also see from Figure 8 that the different clustering themes appear in different time periods, such as #5 COVID-19 pandemic, #8 last mile trip, and #4 identifying profile are the emerging research topics during this period. From a temporal perspective, except Cluster 5, which emerged and formed after the onset of the pandemic, all other clusters had already been established before the outbreak.

As shown from Figure 8, the most co-cited reference was written by Ye RN (2017) (cluster#1, count=47) in which they analyzed data from a survey conducted in Xi’an, China, and aims to quantitatively explore the relative effects of the built environment, travel attitudes, and travel characteristics on commute satisfaction by using structural equation modeling (SEM). Their results show that Attitudes have both direct and indirect effects on commute satisfaction, while the built environment only has indirect effects through influencing commuting characteristics (Ye, & Titheridge, 2017). The second most co-cited article was written by Ding and colleagues (2017) (cluster#0, count=46) in which they drew on a rich dataset of National Household Travel Survey (NHTS) and numerous built environment measurements in the Baltimore metropolitan area. Their research investigates how the built environment affects TMC through influencing car ownership

and travel distance. Therefore, the direct and indirect effects of the built environment on TMC were revealed (Ding et al., 2017)

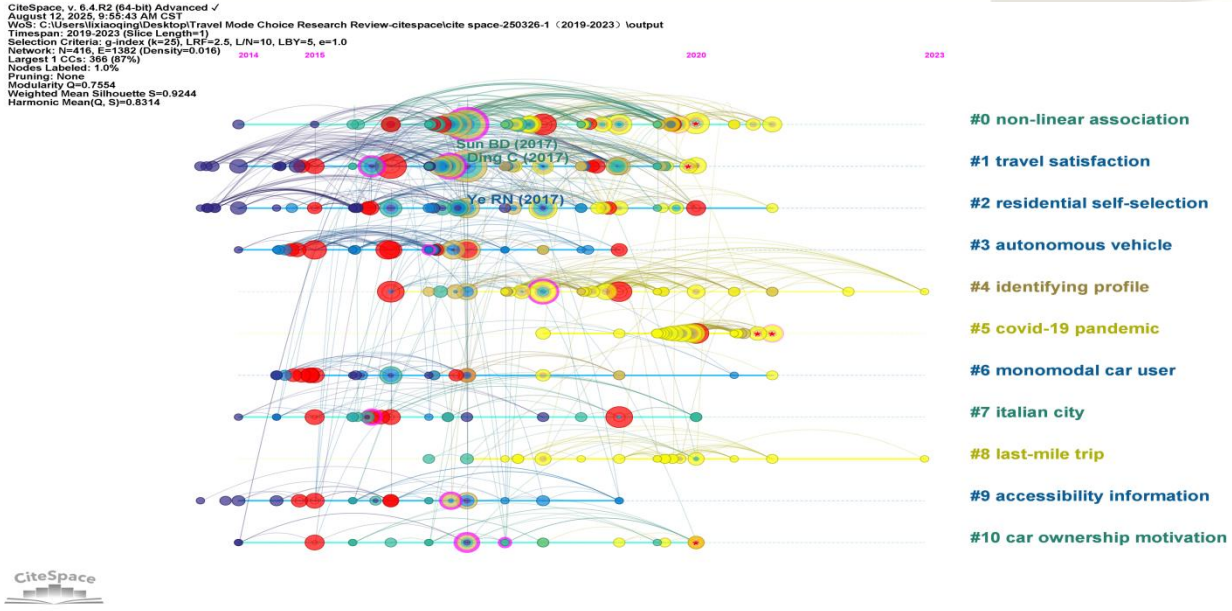

Figure 8. Timeline view of cited articles analysis.

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Table 5 lists the top 10 articles with the highest emergence intensity. Among the 10 emerging literatures, 4 are focused on the theme of autonomous driving, which corroborates the high level of attention it garners in the study of TMC. Bansal (2016) assessed public opinions of and interest in new vehicle technologies to understand Austinites' opinions on smart-car technologies and strategies. Their study shows that respondents perceive fewer crashes to be the primary benefit of autonomous vehicles (AVs), with equipment failure being their top concern. From this research foundation, AVs has drawn the greatest interest among studies of TMC. Krueger (2016) advanced future research on the impacts of AVs travel behaviour by identifying characteristics of potential users of AVs services and eliciting willingness.

In addition to autonomous vehicles, Kamargianni (2015) investigated the subjective and objective factors influencing teenagers' school TMC. Lind (2015) investigated whether the value-belief-norm theory can explain reported travel mode change in the Norwegian urban population and by using structural equation modelling, values and beliefs explained 58 per cent of the variance in personal norms. Ewing (2015) studied varying influences of the built environment on household travel in 15 diverse regions of the United States. Morris & Guerra (2015) examined the relationship between emotions and travel modes, finding that the benefits of cycling may extend beyond the commonly cited health and transportation advantages, and that improving the emotional experience of public transport passengers could be as important as enhancing traditional service functions. These studies have all focused on the factors influencing mode choice for travel. This indicates that research on influencing factors constitutes a significant area of interest within the study of mode choice during this period.

Table 5. Top 10 cited references with the strongest citation bursts

Author	Source	Title	Strength	Begin	End	2019 - 2023
Bansal P, 2016	Transportation Research Part C:	Assessing public opinions of and interest in new vehicle	5.06	2019	2020	

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Author	Source	Title	Strength	Begin	End	2019 - 2023
	Emerging Technologies	technologies: An Austin perspective				
Krueger R, 2016	Transportation Research Part C: Emerging Technologies	Preferences for shared autonomous vehicles	4.76	2019	2020	
Fagnant DJ, 2015	Transportation Research Part A: Policy and Practice	Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations	4.76	2019	2020	
Kamargianni M, 2015	Transportation Research Part A: Policy and Practice	Investigating the subjective and objective factors influencing teenagers' school TMC – An integrated choice and latent variable model	3.86	2019	2020	
Lind HB, 2015	Journal of Environmental Psychology	The value-belief-norm theory, personal norms and sustainable TMC in urban areas	3.86	2019	2020	
Ewing R, 2015	Urban Studies	Varying influences of the built environment on household travel in 15 diverse regions of the United States	3.56	2019	2020	
Heinen E, 2015	Transportation Research Part A: Policy and Practice	The same mode again? An exploration of mode choice variability in Great Britain using the National Travel Survey	3.56	2019	2020	
Simsekoglu Ö, 2015	Transport Policy	The role of attitudes, transport priorities, and car use habit for travel mode use and intentions to use public transportation in an urban Norwegian public	3.56	2019	2020	
Morris EA, 2015	Transportation	Mood and mode: does how we travel affect how we feel?	3.56	2019	2020	
Haboucha CJ, 2017	Transportation Research Part C: Emerging Technologies	User preferences regarding autonomous vehicles	3.36	2019	2020	

Article Structure Variation Analysis

In the co-citation cluster and Structure Variation Analysis (SVA) view generated by CiteSpace, the crimson dotted links represent recently formed or strengthened co-citation relationships, often reflecting intensified connections between active research topics in the latest period, whereas pink links denote earlier, more stable co-citation

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relationships that form the foundational structure of the field but exhibit lower recent activity. Together, these elements highlight both the dynamic evolution of current research fronts and the enduring backbone of the domain's intellectual structure. The red five-pointed star marks references with the strongest citation bursts, indicating works that have experienced a rapid increase in citations over a short period and are thus central to emerging research fronts (Chen, 2012; 2006).

The clusters analysis of cited article are depicted in Figure 9 with various colors, such as Cluster #0 non-linear association, Cluster #1 travel satisfaction, Cluster #2 residential self-selection, Cluster #3 autonomous vehicles, Cluster #4 identifying profile, Cluster #5 covid-19 pandemic, Cluster #6 monomodal car user, Cluster #7 mode choice determinant, Cluster #8 subway station, Cluster #9 accessibility information, Cluster #10 car ownership. As shown in the figure, the crimson-colored connectors indicate a notable recent intensification of inter-thematic linkages between Cluster #1 (travel satisfaction), Cluster #0 (non-linear associations), and Cluster #3 (autonomous vehicles), particularly approaching 2023.

The publication made by Ding, Cheng, and Singleton created new dense links between Cluster #0 non-linear association and Cluster#1 travel satisfaction. Ding et al (2017) examines workplace built environment (BE) characteristics and their predominantly non-linear effects on car mode choice. Cheng (2019) developed a random forest approach, incorporating BE variables, to predict TMC with superior accuracy and efficiency compared to alternative models. Similarly, he investigates non-linear relationships between transportation and subjective well-being (SWB) using structural equation models. Their research explores modal differences and other potential determinants of detailed, multidimensional measures of travel-related subjective well-being, examining variations across modes. In particular, it emphasises the nonlinear relationships between travel behaviour and various influencing factors, employing multiple models and methods, and thereby serves as a bridge connecting Cluster #1 and Cluster #0.

The work of Ye and Kroesen established dense and intricate linkages between Cluster #1 travel satisfaction and Cluster #3 autonomous vehicles. Ye & Titheridge (2017)

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found that attitudes influence commuting satisfaction both directly and indirectly, while the built environment affects it only indirectly through commuting characteristics. Kroesen (2017) showed that over time, mode use and attitudes toward that mode mutually influence each other. Their studies underscore the role of attitudes in travel satisfaction and mode choice/behaviour. With the rise of autonomous vehicles, research on user preferences, attitudes, and public perceptions of new automotive technologies has emerged as a shared focus linking Cluster #3 and Cluster #1.

Additionally, red-star articles in several clusters indicate research hotspots within specific time slices. In Cluster #0, red-star articles compare and summarise differences between logit models and machine learning methods in TMC prediction and behavioural analysis, facilitating expanded research methods and model selection. In Cluster #5, two red-star articles focus more on the pandemic's psychological impacts on TMC, highlighting that perceptions of the disease and lockdown stringency play key roles in shaping behavioural changes. In Cluster #10, highly cited articles examine car ownership's influence on TMC, while the red-star articles assess the welfare impacts of shared mobility and Mobility as a Service (MaaS). Given the timing of their popularity, most red-star articles saw a marked rise in citations starting from 2020 or 2021, peaking in 2023. Thus, machine learning methods, the pandemic's effects and car ownership's influence on the change of TMC, and the welfare impacts of shared mobility and MaaS are all research hotspots and outcomes with transformative potential after 2023.

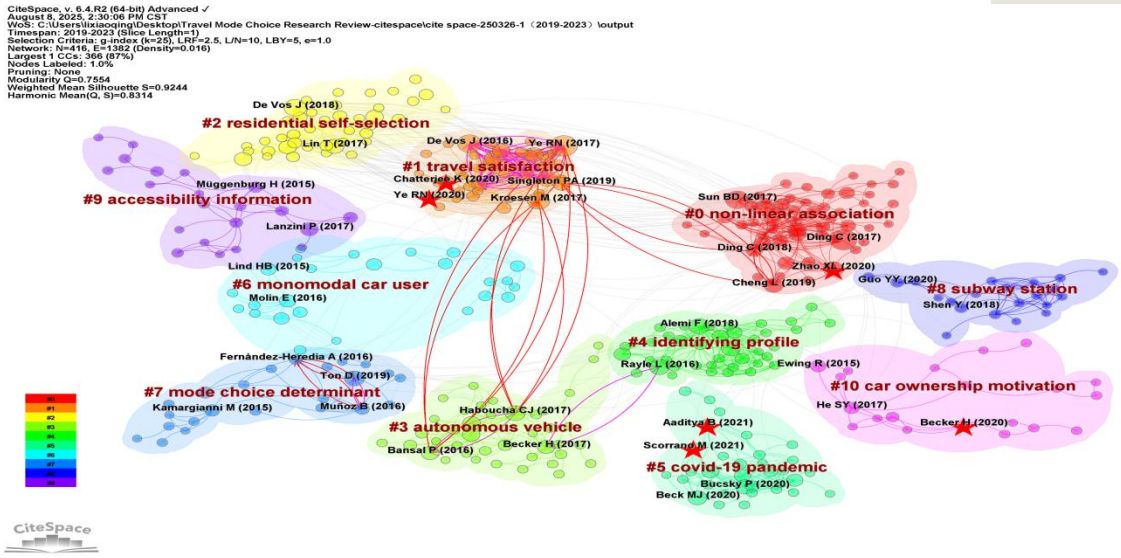

Figure 9. The clusters analysis of cited article (SVA view)

Article Analysis of Cluster 5 COVID-19 Pandemic

To more clearly present the core research themes related to the pandemic in this phase, this study conducted a dedicated literature analysis on cluster #5. As the sixth largest cluster in this study, cluster #5 comprises 33 members and exhibits a high silhouette coefficient of 0.987, indicating strong thematic coherence and focus. The average publication year for this cluster is 2020, suggesting that this research theme emerged following the outbreak of the pandemic and represents one of the most recent waves of scholarly inquiry during this period.

An analysis of the keywords, Major Citing Articles, and Most Cited Articles within this cluster reveals that it primarily focuses on the impacts of the pandemic on mode choice, active travel, and factors such as environment, land use, car ownership, physical health, and teleworking behaviour. These topics constitute the core thematic group of travel behaviour research under the pandemic context. The LLR keyword “COVID-19 pandemic” and the LSI label “COVID-19 public transport recovery,” together with the keyword and literature analysis, point to studies on mode shifts and travel psychology during and after the pandemic. The MI label “safety perception” further

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highlights the crucial role of risk perception and safety awareness in travel decision-making within this theme.

Keyword and theme distribution

Keyword frequency analysis shows that the research themes of Cluster #5 exhibit a multidimensional and intersecting structural pattern. As shown in Table 6, studies on TMC within this cluster primarily focus on non-linear relationships and influencing factors. In terms of travel modes, the emphasis is mainly on active travel and bus services, while the key influencing factors include environmental attributes, land use, car dependence, and physical activity. This reflects the continued influence of pre-pandemic factors, while also highlighting the emergence of new factors such as physical activity. In addition, spatial variations and differences across age and gender groups have also received considerable attention.

Table 6. Top 30 Keywords of Cluster 5

No.	Freq	Keywords	No.	Freq	Keywords
1	107	Non-linear association	16	35	Illustrating nonlinear effect
2	94	Active travel	17	34	Beijing china
3	71	Environment attribute	18	34	Land use densification
4	70	Nonlinear effect	19	34	Nonlinear mediation relation-ship
5	63	Car ownership	20	33	Physical activity
6	52	Travel mode choice	21	32	Equity context
7	44	Land use	22	32	Machine learning algorithm
8	41	Interaction effect	23	32	Travel behaviour
9	38	Boosting approach	24	32	Understanding transit ridership
10	38	Extreme gradient	25	31	Bus service
11	38	Mode choice	26	31	Commuting mode choice
12	37	Car dependence	27	31	Environment characteristics
13	36	Commuting mode choice account-ing	28	30	Environment insight
14	36	Spatial heterogeneity	29	30	Gender difference
15	35	Housing renters transit	30	29	Different age group

Most cited articles and Major citing articles

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Most Cited Articles provides a theoretical and empirical foundation for clusters, forming the early "knowledge core" of research on TMC during the pandemic era. Specifically, Beck & Hensher (2020) examined the early impacts of the pandemic on transport policy and commuting choices. de Haas M et al. (2020) investigated the interaction between teleworking and changes in travel behavior. Abdullah M et al. (2020) developed a behavioural framework for the pandemic, laying the groundwork for subsequent machine learning studies. The effects of the pandemic and lockdown on transport policy and travel behavior, the changes induced by teleworking and policy interventions, as well as the application of machine learning methods, have collectively provided a foundation for further investigation into TMC under the pandemic context. CiteSpace automatically selects “Major citing articles” based on these metrics. If an article exhibits high Coverage combined with high LCS/LCR within a cluster, it is typically included in the "Major citing articles," which helps rapidly identify the most influential and highly connected literature within a given topic. "Coverage" indicates the number of references within the cluster that are cited by the article. A higher number signifies greater representativeness. GCS (Global Citation Score) refers to the total number of citations received by a document across the entire database (e.g., WoS, Scopus), serving as a measure of the article's overall academic impact. LCS (Local Citation Score) denotes the number of citations a document receives within the current CiteSpace dataset, reflecting its position within the thematic network and measuring the article's "centrality" or "core status" within the specific research topic (cluster). Table 7 presents six highly representative citation articles. These studies focus on the short-term impacts of COVID-19 on travel behavior and public transportation systems, revealing shifts in residents' travel patterns during the pandemic. They identify or validate the influence of health and safety risk perception, psychological factors, work from home, and car ownership on mode shift, and explore the role of shared mobility during pandemic periods. These works represent the latest research directions in this field during the pandemic era.

Table 7. Major Citing Articles

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Author (Year)	Title	Finding	Coverage	GCS	LCS
Bwambale (2023)	Willingness to pay for COVID-19 mitigation measures in public transport and paratransit in low-income countries	During the pandemic, typical mode choice factors (costs, travel time, convenience) mattered less; safety measures became more key.	13	7	0
Vallejo-Borda (2023)	Modelling the COVID-19 travel choices in Colombia and India: a hybrid multiple discrete-continuous nested extreme value approach.	In both countries, utility related to active modes (more used) and public transportation (less used) changed during the pandemic.	11	7	0
Loa (2023)	Identifying the determinants of anticipated post-pandemic mode choices in the Greater Toronto Area: a stated preference study.	Highlight the influence of sociodemographic attributes and pre-pandemic travel habits on anticipated post-pandemic mode choices.	9	6	0
Xiang (2023)	Effects of risk perception on commuters' mode choice behaviour during the COVID-19 pandemic: evidence from Shenzhen, China.	Populations with different level of epidemic risk perception have heterogeneity	8	9	0
Zheng (2023)	Examining the interactions between working from home, travel behaviour and change in car ownership due to the impact of covid-19	Those who bought cars during the pandemic, they tended to work on-site more.	8	4	0
Christoforou (2023)	Mode shifts from public transport to bike-sharing in the era of covid-19: riding back to normality.	Certain pre-covid factors (such as weather and type of day, travel purpose) remain influential under COVID-19, Health and safety concerns are key factors that guide fare payers to or from public transport	7	3	0

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Overall, this clustering reveals a newly emerging research direction in TMC that rapidly developed after 2020. It reflects the changes brought by the pandemic to travel behaviour, such as shifts in mode choice, with a focus on the short-term responses and potential long-term impacts on public transportation and travel behaviour. Scholars have employed methods such as non-linear behavioural modelling, psychological surveys, cross-national comparisons, and machine learning to examine how factors including risk perception, teleworking, travel habits, and policy interventions have influenced travel mode shifts during this period. These findings indicate that the pandemic, as a large-scale and far-reaching public health crisis, not only brought tangible changes to travel behaviour and mode choice, transformed the behavioural models underlying individuals' TMC decisions but also expanded and validated the roles of a broader set of internal and external factors in influencing travel mode shifts.

Knowledge map

The second objective of this study was to consolidate the findings from the scientometric review into a comprehensive diagram summarising the knowledge domain of TMC (refer to Figure 10). This diagram encapsulates all the pivotal outcomes and elements of this field, encompassing primary and important journals, countries and institutions, key authors and crucial references, then the part related to COVID-19. Collectively, these discoveries offer a concise overview of the research landscape within this field.

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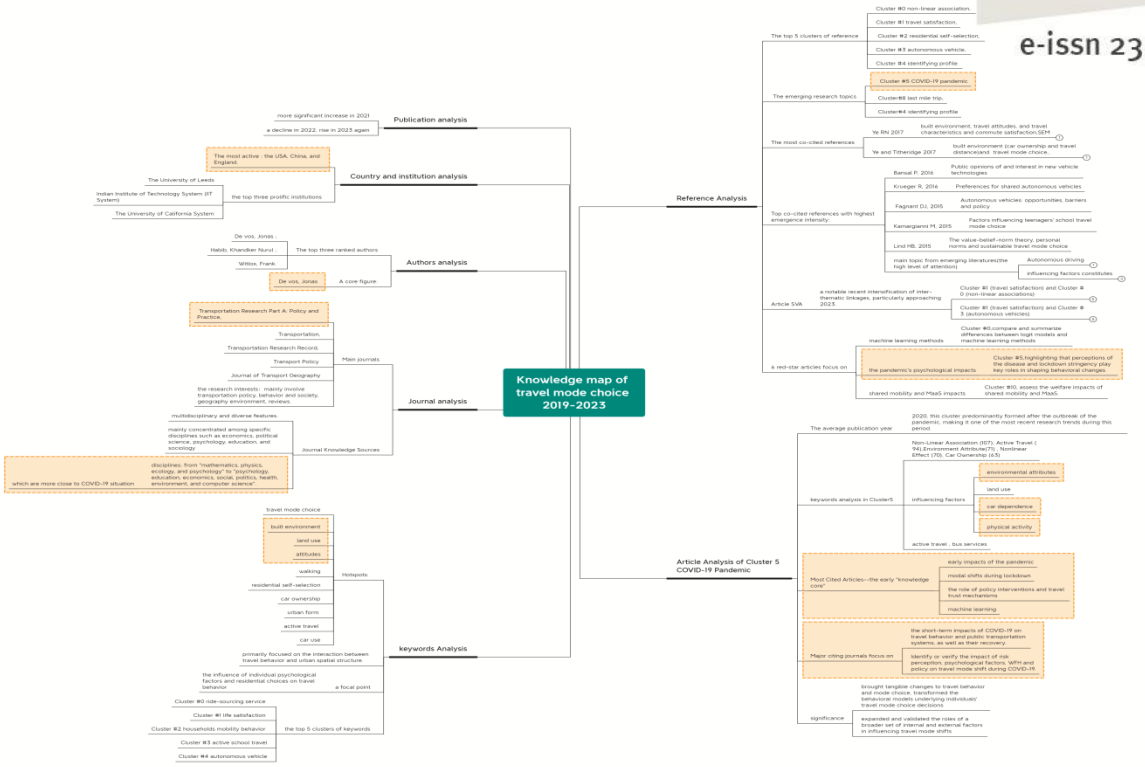

Figure 10. Knowledge map of the TMC research（2019-2023）

Discussion

To better complete the third research objective, the content related to the epidemic in the research results was analysed and discussed.

New pandemic-related clusters have emerged.

During the selected period, research on TMC was still primarily concentrated in pre-existing clusters, includingcluster#0 non-linear association (Size=56， Silhouette= 0.843，Average Year =2018)，cluster#1 travel satisfaction (Size=44，Silhouette= 0.939， Average Year =2017)， cluster#2 residential self-selection (Size=42， Silhouette= 0.819，Average Year =2016)，cluster#3 autonomous vehicle(Size=41， Silhouette= 0.984，Average Year =2016). These clusters are larger in size and were all established before the pandemic. In contrast, Cluster #5 (COVID-19 pandemic), which emerged in 2020, is the newly formed pandemic-related cluster during the study

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period. This timing aligns with the outbreak and gradual escalation of the pandemic in late 2019 and early 2020. The significant impact of COVID-19 attracted considerable research attention, leading to the formation of a new thematic focus within TMC studies.

The pandemic has expanded the range of disciplines, topics, and influencing factors on TMC.

Based on the preceding analytical results, new Developments in TMC during the Pandemic era. The dual-map overlay reveals the emergence of disciplines such as medical and health sciences, and psychology—fields closely related to the pandemic. Literature analysis further indicates that early studies during the pandemic focused on mode shifts, the role of COVID-19, and its influencing factors, forming new research directions and themes. In addition to pre-pandemic factors like the built environment, emerging factors such as health risks and work from home—highlighted by the pandemic—also became important research topics. Therefore, it can be concluded that the pandemic has expanded the scope of TMC research.

Has the impact of the pandemic on TMC faded away? How should this be assessed?

The impact of the pandemic spanned a duration of three years, during which residents underwent significant changes in travel behaviour, and the pandemic exerted profound effects on socioeconomic conditions and transportation operations. The pandemic not only promoted and normalised remote work but also left a psychological imprint on certain residents regarding the risk of contracting diseases through public transit. Furthermore, some households purchased private automobiles or developed habits of driving or cycling during the pandemic—trends that may continue to influence travel patterns for several years after the pandemic era, potentially persisting until a new pivotal event occurs. Therefore, it is reasonable to conclude that the effects of the pandemic are unlikely to vanish entirely in a short time even the pandemic period ends. Thus, how can we determine whether TMC after the pandemic era remains influenced by the pandemic? What are the short-term versus long-term effects, and how long do

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these effects persist? Addressing these questions is crucial for a deeper understanding of the pandemic's long-term impact on TMC, the development of travel behaviour models and strategies for short- or long-term adjustment of residents' travel mode preferences after the pandemic era. These questions should not be examined solely through whether residents have resumed pre-pandemic travel modes or whether passenger volumes for specific modes have recovered. Instead, it should be investigated by analysing whether factors that emerged or gained significance during the pandemic—such as perceived health risks, remote work adoption, psychological changes, policy interventions, behavioural habits, and car ownership—continue to influence residents' mode choices in subsequent time periods. This approach will provide valuable insights for refining residents' travel behaviour in response to the pandemic experience and advancing sustainable transportation systems.

Conclusions

summary

This review conducts a scientometric review using CiteSpace to show a broad view of the field of TMC research from 2019 to 2023 (the pandemic era). 972 WoS academic literature identified under the transportation category. It conducted an analysis of key journals, keywords, authors, institutions, countries, references and a focused analysis of cluster5 COVID-19 pandemic. The results show a knowledge map of TMC research status during the pandemic era. Transportation Research Part A: Policy and Practice, Transportation, Transportation Research Record are main journals in this topic. The USA, China and England are the three countries with high research popularity. The University of Leeds, the Indian Institute of Technology System (IIT System) and the University of California System are the top three prolific institutions. De vos, Jonas; Habib, Khandker Nurul and Witlox, Frank are the top three ranked authors. Among them, De vos, Jonas has made outstanding contributions in this field. Whether from keyword analysis or cluster analysis, the built environment, travel attitude, travel

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satisfaction, autonomous vehicle and related sub-topics have always been the focus of this field.

Besides these main characters, it was also found that a cluster (#5COVID-19 pandemic) emerge newly. Through keyword analysis of this cluster, the hotspots topic including non-Linear association, active travel, and environment attribute revealed clearly. During early pandemic era, researchers focused on the response after the pandemic outbreak and revealed the role of different modes in the spread of diseases, investigated the impacts of COVID-19 on mode shift and how the pandemic restriction policies influence public transport and active travel. Based on these facts, a deeper exploration was conducted to identify or verify the impact of risk perception, psychological factors, WFH and policy on travel mode shift. This provides a useful entry point for examining whether the impacts of the pandemic continue to exert influence in the pandemic-free era.

In summary, COVID-19 brought tangible changes to travel behaviour and mode choice, expanded and validated the roles of a broader set of factors in influencing travel mode shifts. It might be a continued influence. Therefore, future research should further reveal more understanding of TMC in the pandemic-free era and better support future transportation planning and operation management.

Limitations

Several study limitations should be noted. The study only used the WoS database of peer-reviewed journals as the data source, which overlooked grey literature by practitioners which may have yielded different results. Also, using other academic literature databases could have obtained different results. Additionally, the search query was limited to the WoS research category of transportation, which includes only transportation journals that are predominantly English-language, which may have overlooked research published in non-English languages.

To address potential search query bias, for example, a too-narrow or too-broad search term in WoS, the cluster analysis was based on the larger number of underlying co-cited references rather than the original identified articles. However, when conducting the co-cited reference analysis self-citations were not excluded, which may be a

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potential source of bias in the results. There is also a temporal limitation to this study; we only identified the articles from 2019 to 2023, and from the time of conducting the study to article submission an additional papers have been published in the field. Although this is just one part of the TMC research field, there is scope for analysing research of other subtopic clusters identified in this study.

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